

Comment on “On Phase Selective Quantum Eraser” (arXiv:1501.00817 [quant-ph])

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Abstract

In a recent interesting article A. Heuer, G. Pieplow, and R. Menzel discuss a quantum-eraser experiment to investigate the complementarity of wave-like and particle-like behavior of photons. I would like to draw your attention to the fact that the very same experimental setup was suggested in a previous paper, and take advantage of this opportunity to examine some aspects of this controversial subject.

In a recent interesting article [1] A. Heuer, G. Pieplow, and R. Menzel (HPM) discuss a quantum-eraser experiment. To “demonstrate a quantum eraser protocol for the complementarity of wave-like and particle-like behavior of photons” they introduce an extra Mach-Zehnder interferometer in an experiment on induced coherence without induced emission [2]. In fact, the very same experimental setup was suggested in a previous paper [3]. In the HPM experiment, whenever it is possible to know which crystal emits the pair of photons, there is no interference. On the other hand, when this information is erased, interference can be observed. Since the concept of the quantum eraser was introduced [4], many experiments have been proposed and performed [5]. What makes the experiment suggested in [3] particularly interesting is that we have a situation in which, apparently, the idler and signal photons are emitted by different crystals. Since the pair of photons is supposed to be generated when a photon of the pumping laser is split in two inside a crystal (an idler and a signal), we are facing a mind-boggling situation. This strongly indicates that, as emphasized by Lamb [6], we have to be very careful when dealing with the photon concept. That a single photon can be spread throughout the electromagnetic field of independent sources was already implicit in an experiment on the interference of attenuated light emitted by independent lasers [7], even though it involved no authentic one photon (Fock) states, as would be the ideal. It is well established that a photon can disclose wave-like and particle-like features. On the other hand, the idea that a photon can *behave* as a wave *or* as a particle,

depending on the kind of experiment that is being performed, has generated considerable confusion, the most well known case being the Wheeler delayed-choice experiment [8]. In this experiment, single photons impinge, successively, on a Mach-Zehnder (M-Z) interferometer. If the second beam-splitter (BS) of the interferometer is in place (“closed” interferometer), interference can be observed; for instance, we can have the photons always emerging on the same output port; if it is removed (“open” interferometer), the photons will always be found following one arm of the interferometer or the other, never both at the same time [9]. *Apparently*, the photon behaves as a wave in the first case and as a particle in the second. However, we are dealing with a quantum entity, not a classical one, and the attempt to directly transpose our macroscopic experience into the microworld may be misleading. Surely, a photon can disclose wave-like and particle-like behaviors, which is not the same as being able to “adapt” its behavior according to the experimental setup. The idea behind the Wheeler delayed-choice experiment (although not necessarily explicitly assumed) is that, by deciding to remove, or not, the second BS after the passage of the photon through the first BS, we can try to “cheat” the photon, so to speak, which will not “know” if it is impinging on an open or a closed M-Z interferometer. For instance, when it impinges on the first BS, we keep the second BS removed, but, while it is still inside the interferometer, we put the second BS in place. It is implicit conjectured that the photon might “decide” to behave as a particle or as a wave when it impinges on the first BS (somehow it would “know” whether the second BS is in place or not) [10]. Naturally, this appears to be a preposterous idea, and goes against the essence of quantum mechanical formalism (QMF). According to QMF, the impinging photon is represented by a ket that is split at the first BS, and the way it is split does not depend on the second BS being in place or not, that is, on the M-Z interferometer being open or closed. As has been correctly pointed out recently [11], delayed-choice experiments do not imply retrocausality. In fact, what is essentially new – and this has to do with the nonlocal features of the quantum world – is that whenever the photon is detected on one of the arms of the interferometer the ket following the other arm is nullified; on the other hand, if the photon is not detected on one of the arms, it will necessarily be detected on the other (negative or null-result experiment [12]). Situations in which a photon seems to behave neither as a particle nor as a wave, making evident the impossibility of tracing back the photon path have also been discussed [13]. We can also consider a M-Z interferometer in which the mirrors are replaced by BSs, which we can designate as an “open-closed” interferometer. In this case, how is the photon supposed to behave? Will it plunge into a state of internal confusion, incapable to decide what to do? Or, will it take its decision (to behave as a particle or as a wave) before impinging on the first BS? Undoubtedly, if we insist in following this line of thought, we will end up adopting an animist vision of reality.

It is important to stress that ontic interpretations of the pilot-wave kind [14] cannot a priori be discarded. In this case, particles would have well-defined trajectories, being guided by waves. But, also here, we cannot cheat this wave *and* particle entity by doing a delayed-choice experiment. In conclusion, delayed-

choice experiments [15] may justly be considered impressive technical achievements, but are of little use to unveil the mysteries of the quantum world or to challenge realism [16].

References

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- [8] Article by J. A. Wheeler, reprinted in *Quantum Theory and Measurement*, J. A. Wheeler and W. H. Zurek (eds.), Princeton University Press, Princeton (1983).
- [9] It is also possible to acquire information about the path with no need to remove the second BS or block one of the paths. In this case, interference is also lost: L. C. Ryff and P. H. S. Ribeiro, Phys. Rev. A. **63**, 023801 (2001); L. C. Ryff, Z. Naturforsch. **56a**, 155 (2001), *presented at the 3rd Workshop on Mysteries, Puzzles and Paradoxes in Quantum Mechanics, Gargnano, Italy, September 17-23, 2000*. One of the experiments discussed in my presentation in the workshop has been used by W. T. M. Irvine, J. F. Hodelin, C. Simon, and D. Bouwmeester, Phys. Rev. Lett. **95**, 030401 (2005) for the realization of Hardy’s thought experiment (L. Hardy, Phys. Rev. Lett. **68**, 2981 (1992)). Actually, after my presentation, Vaidman, that was present at the workshop, came to talk with me to draw my attention to the fact that my proposal could be used to realize Hardy’s experiment. For sure, Irvine, Hodelin, Simon, and Bouwmeester were unaware of my proposal.

- [10] Actually, according to Wheeler (ref. [8]): "No elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon"; and, "The past has no existence except as it is recorded in the present. By deciding what questions our quantum registering equipment shall put in the present we have an undeniable choice in what we have the right to say about the past"; and still, "Useful as it is under everyday circumstances to say that the world exists 'out there' independent of us, that view can no longer be upheld." Therefore, it is far from clear, if we assume this anthropocentric attitude, what is the purpose of the delayed-choice experiment. What difference does it make to put or to remove the second BS after the photon has already passed the first BS? What is to be expected from this? What does it prove (the confirmation of the quantum mechanical predictions) with respect to the dispute between the ontological (realist) and the epistemological (antirealist) points of view?
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- [13] L. C. Ryff, *Found. Phys. Lett.* **10** (3), 207 (1997); L. C. Ryff, *Quant. Semiclass. Opt.* **10**, 409 (1998); L. C. Ryff, in *Causality and Locality in Modern Physics*, G. Hunter, S. Jeffers, and J-P. Vigi er (eds), Kluwer Academic, Dordrecht (1998), where it is shown that in some situations the attempt to trace back the behavior of the photon leads to a contradiction.
- [14] F. Selleri, in *The Wave Particle Dualism*, S. Diner et al. (eds), Kluwer Academic, Dordrecht (1984); T. Norsen, arXiv:quant-ph/0611034 (2006).
- [15] X-s. Ma, J. Kofler, and A. Zeilinger, arXiv:1047.2930v2 [quant-ph] (to be published in *Rev. Mod. Phys.*), for a recent review on the subject of delayed-choice experiments. See also L. C. Ryff, arXiv:0303082 [quant-ph], where it is shown why the statement "in delayed-choice entanglement swapping experiments one can demonstrate that whether two quantum systems are entangled or separable can be decided even after they have been measured" is disputable.
- [16] In a popular talk about the Bose-Einstein condensate, given at the annual meeting of the German Physical Society in Hannover, March 2003, the Nobel prize winner Wolfgang Ketterle told the public that is very hard to understand quantum mechanics but after several years of physical practice one gets used to preparing waves and detecting particles. (See, B. Falkenburg, *Particle Metaphysics*, Springer, Berlin (2007), p.280)